Town of Crested Butte, Colorado

Energy, Materials, and Greenhouse Gas Emissions Inventory: 2017 Baseline & 2030 Forecast

Center for Environment and Sustainability
Community Solutions Incubation+Innovation (CS2I) Lab
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Executive Summary

The Town of Crested Butte and Western State Colorado University's Community Solutions Incubation+Innovation (CS2I) Lab have partnered to complete: 1) a 2017 energy use and GHG emissions baseline inventory and footprint for Crested Butte, and 2) forecast community-wide GHG emissions to year 2030. This work has been completed by applying latest and global best practices for community-scale energy and GHG emissions accounting. The inventory accounts for in-boundary activities resulting from residential buildings, commercial buildings, surface travel, waste landfilling, and water & wastewater electricity use. Beyond the inventory, the footprint also accounts for out-of-boundary energy uses and GHG emissions rooted in the key essential activities of: fuel refining (for transportation), cement production (for built environment), and food production.

Applying variables that included demographic, economic, and technical infrastructural changes, the CS2I Lab also completed a GHG emissions forecast to 2030. The forecast is intended to be a tool for the local government in having a reference point for future actions, thereby allowing for continued tracking over time. Note, the 2030 forecast is completed for Crested Butte's in-boundary inventory sectors (residential buildings, commercial buildings, surface travel, waste landfilling, and water & wastewater electricity use).

Results – Energy and GHG Emissions Baseline

This assessment estimates GHG emissions associated with Crested Butte in 2017 amount to:
In-Boundary Inventory *(Scopes 1+2)* associated with residential + commercial buildings, surface travel, waste landfilling, and water & wastewater electricity use = **40,088 mt CO_2e**

Essential Out-of-Boundary Flows *(Scope 3)* associated with fuel refining, cement production, and food production = **10,958 mt CO_2e**

TOTAL Crested Butte Community-Wide Footprint *(Scopes 1+2+3)* = **51,046 mt CO_2e**

Figure ES.1 shows the allocation of Crested Butte's GHG emissions footprint across sectors. Observe that buildings energy use amounts to **61%** of the community's footprint, with electricity alone being **48%** of the footprint.

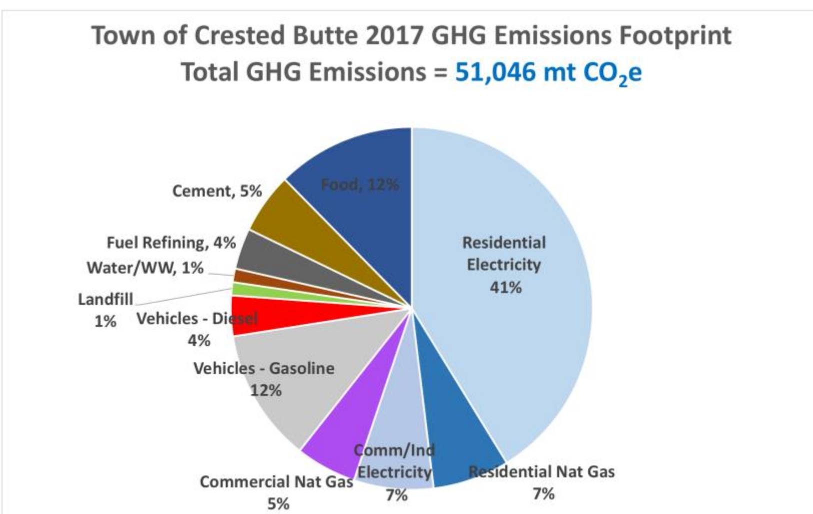

Figure ES.1: Crested Butte 2017 GHG Emissions Footprint.

Results – Energy and GHG Emissions 2030 Forecast:

The use of high-quality publicly available demographic, economic, and technological data were applied in creating a 2030 forecast for Crested Butte. The forecast reveals that Crested Butte's in-boundary GHG emissions are projected to increase slightly from 2017 levels of 40,088 mt CO_2e to 40,129 mt CO_2e in 2030. At 22.8% increase, Surface Travel is projected to increase the most during this period. See Figure ES.2.

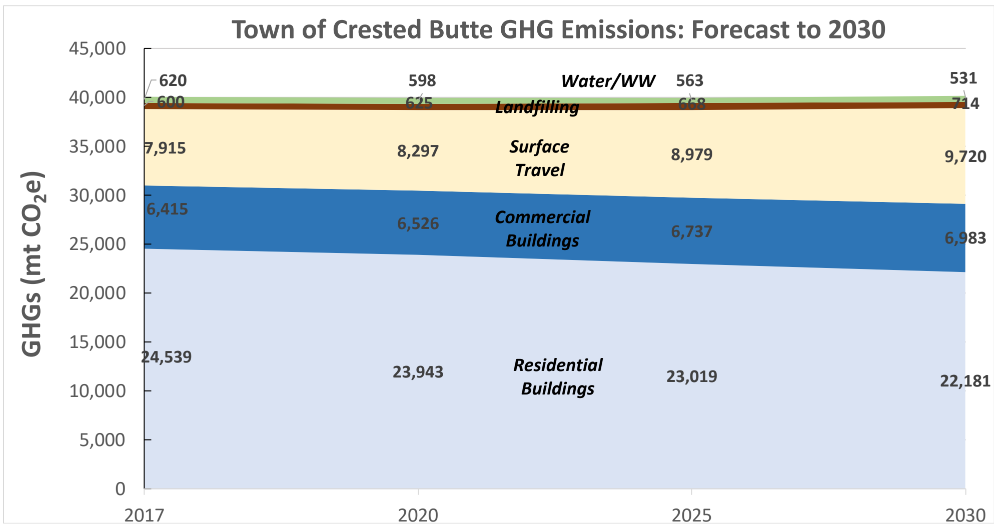

Figure ES.2: Crested Butte In-Boundary GHG Emissions 2030 Forecast.

1. Introduction and Background

Sustainability and resilience are two concepts that are becoming increasingly more familiar for and common parlance in local governments. Sustainability is often rooted in the "three E's" (Economics, Environment and Equity), and resilience is measured by the ability of a system to respond or return to functioning state post-shock. All the while, in order for maximum relevance, each concept ought to be placed and defined within the local community's context.

To this end, Dr. Abel Chávez and his CS2I Lab (Community Solutions Incubation+Innovation) team at Western State Colorado University (Western) partner with local governments and their constituents to develop their respective contexts and coupled narratives around energy, materials, and greenhouse gas (GHG) emissions. The CS2I Lab team also employs robust data processes to create energy and GHG emissions forecasts that are employed in long-term sustainability, resilience, and community planning.

The following report describes the results from energy and GHG emissions baselining and forecasting conducted through the partnership of Western and the Town of Crested Butte, Colorado. First, a brief introduction into baselining guiding principles and global best practices are presented. Second, results from the energy and GHG emissions baselining are shared. Last, highlights from the energy and GHG emissions forecasting to year 2030.

The reader should note the important difference between inventory and footprint. An inventory is boundary limited in that only activities from within the community are considered. However, the reality is that communities are far more complex than their in-boundary activities and depend on a vast number of supply-chains. A footprint therefore expands beyond the community boundary to consider a series of inexorably linked flows, that are imperative for community and economic function. Additionally, while the expansion from inventory to footprint will also yield a 'larger' estimate of a community's energy and GHG emissions, cost-effective actions may enhance efficiencies across out-of-boundary activities while preventing shifting of impacts, thus yielding a more holistic and realistic representation of the community.

1.1 Energy & GHG Emissions Baselining and Forecasting

As our economic system globalizes, the chains through which demand for energy and materials are provisioned are increasingly longer, more complex, and often more abstract. Thus, such energy and GHG emissions baselines are a useful mechanism for assessing a series of fundamental community questions including: "how much of particular energy type is used by vs. in the community and for what purposes?"; "how secure are the community's energy sources, and where are resilience opportunities?"; or, "can we continue growing our economy in a sustained manner?". A strong, robust, and community-driven baseline and forecast is a tool for all government-level departments in their respective and collective planning efforts, yielding an understanding of the possibilities towards building a strong local economy that generates jobs for its healthy residents, who are able to reap the benefits of energy efficient and renewable technologies.

In addition to the energy and GHG emissions baseline for year 2017, this report also summarizes a business-as-usual (BAU) forecast of Crested Butte's energy and GHG emissions to year 2030. Such a forecast allows for informed planning with innovative actions which can drive specific actions, all while being able to track the effects of actions in real-time, and long-term.

1.2 Greenhouse Gases (GHGs)

There are several greenhouse gases that are captured in a GHG emissions Baseline. GHGs include carbon dioxide ***(CO_2)***, methane ***(CH_4)***, nitrous oxide ***(N_2O)***, and three replacements for chlorofluorocarbons ***(CFC)*** (HFCs, PFCs, SF_6) that have mostly been phased out as a result of the 1989 Montreal Protocol. CFCs are typically small, unless significant industrial production of these chemicals occurs within the community.

Dominant GHGs: In the U.S., carbon dioxide ***(CO_2)***, methane ***(CH_4)***, and nitrous oxide ***(N_2O)*** emissions account for 97% of GHG emissions (EPA, 2016).

Sources of GHGs: There are a number of prominent GHG sources across communities. Carbon dioxide ***(CO_2)***, the largest contributor, is frequently produced from the combustion of fossil fuels in furnaces, power plants, and vehicular transportation. Methane ***(CH_4)*** is most often produced from waste decomposition (naturally or in landfills), enteric fermentation (cattle), and from fugitive emissions in natural gas pipelines. Nitrous oxide ***(N_2O)*** is most often emitted during wastewater treatment and agricultural soil and manure management.

GHGs Global Warming Potentials: GHGs are classified by their ability to trap heat in the atmosphere, and thus are assigned a value called Global Warming Potential (GWP). As a result, GHGs from different sources are then aggregated by their respective GWP and reported as a whole on a common basis known as metric tons of carbon dioxide equivalent (mt CO_2e). Table 1 shows the GWP for the top three greenhouse gases in the atmosphere. Note that methane has 28 times more potential to trap heat than carbon dioxide, and nitrous oxide has 265 times more potential.

Table 1: Global Warming Potentials

Greenhouse gas	Chemical Formula	Global Warming Potential
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	265

1.3 Background: Energy and GHG in Crested Butte

Crested Butte is one, of three, semi-urban areas of Gunnison County. The other two semi-urban areas are City of Gunnison, and Mt. Crested Butte. As a whole, Gunnison County, a mostly rural county, is located in southwest Colorado. Total Gunnison County population is estimated at 16,145 people, with about 50% of the population concentrated in the semi-urban areas, of which 1,648 people are estimated to live in Crested Butte (Census, 2016). With an average elevation of 7,700 feet above sea-level, the valley is also one of the coldest in the continental U.S., averaging 37°F. The community is a place with rich diversity, where its people are proud to call home. To assist in imagining the menu of novel development pathways, energy and GHG emissions analysis can reveal insights for stakeholders about key critical paths, while creating new and novel opportunities for all.

Often, energy and GHG emissions analyses are placed under the broad nomenclatures of *Energy Plan*, or *GHG Emissions Inventories,* or *Footprints*. In 2008, a group of community members released the Upper Gunnison River Watershed Greenhouse Gas Emissions Inventory (UGRW) applying 2005 activity data to a boundary defined by the watershed (ORE, 2008). In 2009, a separate study that borrowed data from the UGRW yielded the Energy Action Plan for The Town of Crested Butte (EAP, 2009) as a tool to stimulate action towards energy use reduction. This GHG emissions baseline and forecast obtained new and current data, while also applying present energy and GHG accounting methodologies as detailed in recently released global standards (i.e., ICLEI, 2012; PAS, 2013; GPC, 2014). Thus, the objectives of this study included:

- In partnership with Crested Butte, conduct a baseline inventory and footprint of community-wide energy use and GHG emissions;
- Understand key sources of use and opportunity across sectors associated with Crested Butte activities;
- Explore innovative actions that Crested Butte can promote to its policymakers and constituents in efforts of economic development, leadership & innovation, business opportunities, resource conversation, and energy efficiency.

Following is a detailed description and findings of our analysis.

2. GHG Inventory Methodology

2.1 Method and Scopes

This Energy and GHG Inventory for the Town of Crested Butte is completed using the latest community-based methods (ICLEI, 2012; PAS, 2013; GPC, 2014), which Dr. Abel Chávez helped inform and author. These latest methods delineate and describe many important community details around in-boundary (within jurisdictional boundary), and out-of-boundary activities – often reported using the Scope framework. Of the three scopes (Scope 1, 2, 3), Scope 1 are those from purely in-boundary activities, i.e., on-site combustion of fuels (natural gas combustion in furnaces, or vehicle fuel). Scope 2 emissions are usually out-of-boundary resulting from purchased electricity that is generated beyond the community boundary. Last, Scope 3 includes other "optional" out-of-boundary activities crucial for a community (e.g. water, food, fuels, and shelter).

In general, there are three types of approaches to community scale energy, material, and GHG emission accounting, each of which yields unique narratives and policy options. The three are:

- Purely Territorial *(Scope 1)*;
- Expanded Production *(Scope 1, 2, 3 as related to 'production')*; and
- Consumption-Based *(Scope 1, 2, 3 as related to 'consumption')*.

Figure 1 (adapted from Chavez et al., 2013) illustrates these flows in schematic form. This effort mostly reflects a purely territorial (Scope 1), plus Scope 2, with focused production Scope 3, as recommended in global protocols. In addition to the results in this report, consumption-based accounting may also reveal additional policy options available to the community.

2.2 In-Boundary Activities

In-boundary activities accounted include the following.

- **BUILDINGS:** Use of electricity and natural gas in residential and commercial buildings in the community. The uses of these fuels are converted to GHG emissions via each fuels' emissions factor.
- **SURFACE TRANSPORT:** Use of gasoline, diesel by personal and commercial vehicles in the community. Specifically captured as tailpipe GHG emissions from operating vehicles

within the community.

- **WATER and WASTEWATER:** The amount of electricity used in pumping and treatment of water and wastewater used in the community.
- **WASTE LANDFILLING:** Amount of waste landfilled in the community by residential and commercial/industrial sectors. Best practices from EPA's WARM are used for estimating waste GHG emissions.

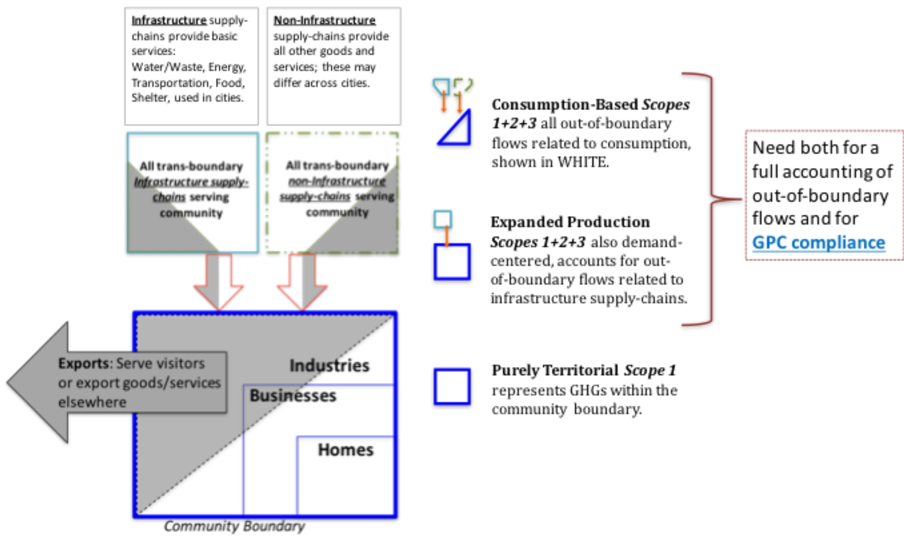

Figure 1: The three fundamental types of GHG accounting approaches for communities.

2.3 Out-of-Boundary Activities

Despite the fact that a community may report a larger GHG footprint upon including Scope 3 activities, there may also be cost-effective actions that can be taken to enhance efficiencies across Scope 3 emissions. The following out-of-boundary activities, when added to in-boundary activities, yield a holistic account of a community's GHG emissions footprint:

- **INFRASTRUCTURE SUPPLY-CHAINS:** This includes energy use and embodied GHG emissions from producing key materials such as water (when trans-boundary), energy, transport fuels, food, and shelter (cement for concrete), necessary to support life and economic development in the community.
- **NON-INFRASTRUCTURE SUPPLY-CHAINS:** These are associated with the provisioning of all other goods and services, such as financial, health, or educational type of services. Though not accounted for in this report, they can provide additional insights.

2.4 Assessed Sectors

To better communicate a community's overall energy use and GHG emissions, classifying energy end-use in three different sectors is most comprehensible in community-wide communications. Thus, noting that the adopted approach is a 'production' based approach, here we report energy use and GHG emissions in the following three sectors:

- **Buildings Sector:** Energy use (electricity, and natural gas) in residential and commercial buildings.
- **Transportation Sector:** Energy (gasoline, and diesel) used in personal and commercial

vehicles. Often referred to as Pump-to-Wheels (PTW).

- **Materials and Waste Sector:** Energy use and associated GHG emissions from producing critical infrastructure materials (food, energy, water, cement) and waste landfilling.

2.5 Required Data and Benchmarks

In order to adequately complete the 2017 baseline for Crested Butte, the following data were gathered (see Table 2). In addition to these data, benchmarks were computed to validate and identify possibly spurious data points and determine key community efficiencies.

Next, to convert energy and material use to GHG emissions, GHG Emissions Factors (EF) are employed. GHG EFs are based on latest technological understanding and represent the amount of CO_2e (carbon dioxide equivalents) emitted per unit of the unit used. For example, kg CO_2e emitted per unit kWh of electricity consumed (or kg CO_2e/kWh).

Last, total **GHG** emissions are computed as the product of how much is consumed (**MFA**) and the GHG emissions per unit of the product consumed (**LCA**), or **GHG** = **MFA** X **LCA**. Thus, each sector's CO_2e emissions can be summed to find the total community-wide emissions.

Table 2: Required Energy Data and Computed Benchmarks for completing a community's baseline energy and material 'in-boundary' inventory.

Sector	Required Energy Data	Computed Benchmarks
Buildings *(Residential, and Commercial)*	• Electricity: total kWh • Natural gas: total therms (or BTU) • Other Fuels, as applicable	Residential Intensity: kWh/HH/mo therms/HH/mo kBTU/HH/mo Commercial/Industrial Intensity: kWh/job/mo therms/job/mo kBTU/job/mo
Surface Transport	• Gasoline: gallons used/purchased • Diesel: gallons used/purchased • Vehicle Miles Traveled (VMT)	VMT/person/day gallons-gasoline/cap/yr gallons-diesel/cap/yr
Landfilling	• Waste landfilled • Characterized waste landfilled	tons-waste landfilled tons-waste landfilled/capita

3. 2017 Town of Crested Butte Energy and GHG Emissions Baseline Inventory

This GHG Emissions Inventory and Footprint summary report is intended to serve as a baseline of energy use and GHG emissions for Crested Butte in 2017. It is Dr. Chávez's intent that the Town of Crested Butte have the necessary information for informed economic and environmental innovation across the community and throughout the valley. As the Town proceeds to, and continues to, embark on triple-bottom line actions, Western's CS2I Lab team led by Dr. Chávez, will be able to assist the community in tracking the progress towards integrating infrastructure efficiencies, reducing environmental impacts, and the economic and social benefits that come as a result of such actions.

3.1 Reporting year

This analysis was completed for 2017 based on consultations with the Town, and assessment on most recent available data. Following are the summarized results for energy and GHG emissions relating to the sectors of:

- Buildings
- Surface Travel
- Water/Wastewater
- Waste and *selected* Materials

This baseline can be referenced, and the effects of local actions can be tracked, in assessing the Town's goals progress moving forward. For each sector, raw activity/use data are presented, GHGs are computed and reported in metric tons of carbon-dioxide equivalent (mt CO_2e), and data benchmarks are quantified and compared to relevant Gunnison County, and State of Colorado metrics.

3.2 Buildings Sector

3.2.1 Buildings MFA: Energy Use

The buildings sector reports electricity, and natural gas used by residential, and commercial buildings. These data were obtained from the following: Electricity from Gunnison County Electric Association (GCEA) for 2017. Natural Gas from Atmos Energy for 2017.

Next, using socio-demographic data pertaining to population (from Colorado's Department of Local Affairs (DOLA)), households (from the U.S. Census), and employment (from the Gunnison Valley Housing Needs Assessment), building energy use intensities were computed as shown in Table 2. Thus, the computed building energy use intensities for Crested Butte were benchmarked with parallel Gunnison County, and State of Colorado metrics reported by the Energy Information Administration (EIA) State Energy Data System (SEDS). The resulting metrics for Crested Butte, Gunnison County, and the State of Colorado are shown in Table 7.

3.2.2 Buildings LCA: GHG Emissions

GCEA's EF was retrieved from Tri-State Generation and Transmission Association (Tri-State) – GCEA's sole supplier – and reported as 0.74 kg CO_2e/kWh (Tri-State, 2015). For natural gas, the EF value applied was 5.3 kg CO_2e/therm (EPA, 2014) corresponding to the national default values, which does not generally change according to region. Therefore, total energy use (or MFA), is multiplied by that fuel's respective emissions factors (or LCA), to compute the total GHG emissions, resulting in **30,954 mt CO_2e** for the total buildings sector; residential buildings generating **24,539 mt CO_2e**, and commercial buildings **6,415 mt CO_2e**. See Table 3 for added details.

Table 3: 2017 Buildings Energy Use and GHG Emissions – Town of Crested Butte.

Residential Energy	**2017**
Total Population	1,628
Households	1,083
GCEA Grid Electricity use (kWh)	30,118,932
Natural Gas use (therms)	659,490
Total Residential GHG emissions (mt CO_2e)	**24,539**
Commercial Energy	**2017**
Jobs	4,208
GCEA Grid Electricity use (kWh)	5,190,641
Natural Gas use (therms)	525,550
Total Comm. GHG emissions (mt CO_2e)	**6,415**
Total Buildings GHG Emissions (mt CO_2e)	**30,954**

3.3 Transportation Sector

Transportation energy use in Crested Butte results from a principal source:

1. **Personal and Commercial Vehicles (Surface Travel)**

Summary statistics for Crested Butte's transportation sector are presented in Table 4 below.

3.3.1 Surface Travel and Vehicle Intensity

Estimating surface travel energy use for the Town of Crested Butte employed the following 2015 data. First, annual vehicle miles traveled (VMT) were retrieved from the Colorado Department of Transportation (CDOT) at the scale of Gunnison County using the VMT tool (CDOT, 2015), amounting to a county-wide estimate of 153.9 million VMT, or 26.3 miles/person/day. Next, we applied the county average of 26.3 miles/person/day to estimate the total vehicles miles in Crested Butte as 15,596,511 miles. Then, using total vehicle miles with the percentage of national VMTs by vehicle type (e.g., light duty vehicles, trucks, bus, etc.), the Town's VMTs were allocated to the same vehicle types, resulting in estimated VMTs by vehicle type in Crested Butte. Last, total fuel usage, in gallons of gasoline and diesel, were computed via the ratio of VMT (miles) to fuel economy (miles per gallon). See Table 4 for fuel estimates.

The above approach was validated in the following manner.

a. CDOT VMTs were compared to similar statistics reported by HPMS and EPA which uses average roadway vehicle-miles in both urban and rural U.S. counties. Our approach produced no computable differences. 27.2 miles/cap/day from HPMS, compared to 26.3 miles/cap/day our estimate.

b. Fuel use, per capita gallons of gasoline and diesel, respectively, were benchmarked to State metrics; acceptable and only minor differences noted. See benchmarking table, Table 7.

3.3.3 Emissions from Gasoline, and Diesel

Transportation fuel (gasoline, and diesel) combustion emissions factors were obtained from EPA (2014) – the following factors were used in this baseline inventory: gasoline = 8.87 kg CO_2e/gallon, and diesel = 10.22 kg CO_2e/gallon. Upon multiplying fuel used by type (MFA) by the respective EF (LCA), the following estimates of GHG emissions were computed for Crested Butte: Gasoline = 6,068 mt CO_2e; Diesel = 1,847 mt CO_2e, for a total transportation GHG emissions of **7,915 mt CO_2e**. Table 4 provides additional details.

Table 4: Transportation sector energy use and GHG emissions.

Surface Travel	2015
Annual Vehicle Miles Traveled (VMT)	15,596,511
VMT/person/day	26.3
Annual Fuel Use	
Gasoline (gallons)	684,224
Diesel (gallons)	180,736
Total Surface Travel GHG Emissions (mt CO_2e)	**7,915**

3.4 Materials and Waste Sector

As recommended by global community protocol, an expanded production footprint must account for materials from several key sources of GHG emissions including: fuel refining, food production, cement, water & wastewater, and municipal solid waste (MSW). This study accounted for this full suite of sectors, aligning well with global protocols.

3.4.1 Water & Wastewater

The GHG emissions associated with water & wastewater utilities in Crested Butte account for the electricity used in water pumping and wastewater treatment; two of the major sources covering a large portion of this sector's GHGs. Data on the community's electricity use in water & wastewater operations were supplied directly by the Crested Butte Public Works Department. GCEA's electricity EF was retrieved from Tri-State and reported as 0.74 kg CO_2e/kWh (Tri-State, 2015). As a result, water related operations released 119 mt CO_2e, and wastewater operations released = 501 mt CO_2e, for a sector total of **620 mt CO_2e**.

3.4.2 Municipal Solid Waste

Statistics on the municipal solid waste (MSW) landfilled by Crested Butte were retrieved from Waste Management. These data reported the community generated 643 tons of MSW in 2017, though 466 tons of MSW were landfilled – or 177 tons of MSW recycled. Thus, only the landfilled portion of MSW is considered in GHG emissions estimated. As result of applying the EPA's WAste Reduction Model (WARM) to estimate GHG emissions from solid waste as a result of anaerobic breakdown of biodegradable material, and selecting mixed MSW with no flaring in WARM, it is estimated that **600 mt CO_2e** are emitted from waste landfilling in Crested Butte.

3.4.3 Fuel Refining

GHG emissions factors for fuel refining, or Wells-to-Pump (WTP), were retrieved from Argonne National Laboratory's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model (ANL, 2016). The corresponding values are: gasoline = 2.0 kg CO_2e/gallon, diesel = 2.65 kg CO_2e/gallon, and jet fuel = 2.65 kg CO_2e/gallon. As a result, fuel refining associated with Crested Butte's surface travel emitted: gasoline = 1,382 mt CO_2e, and diesel = 480 mt CO_2e, for a total of **1,862 mt CO_2e**.

3.4.4 Cement in Concrete

While a community uses a number of construction materials throughout its built environment, global protocols recognize cement as a material used in high amounts, and the material with high energy and GHG intensities. National Renewable Energy Laboratory's (NREL) Life Cycle Inventory Database reports that Portland cement production emits 0.93 kg CO_2e/kg cement (NREL, 2016). Cement flows in Crested Butte were estimated by first coupling State financial data for the cement sector (NAICS 3273) from Census (2016), where total sales are estimated as $912.6 million, with the average cost of cement ($90/mt cement). Then, the State's use of cement flows were allocated to Crested Butte via the proportion of Crested Butte-to-State population, arriving at **2,771 mt CO_2e** for cement GHG emissions attributed to Crested Butte.

3.4.5 Food Consumption

Food is one more essential flow to be captured in community footprints. Like the other materials sectors, food is not usually produced in large amounts within the community's limits; on the contrary, there are many miles between food's point of production and its consumption. Thus, the embodied energy from food and food packaging is determined as follows. The Consumer Expenditure Survey (CES) provides average annual household food expenditures, estimated at $3,245/HH/yr for Gunnison in 2015, after adjusting for inflation (BLS, 2015). The emissions factor for food production is estimated at 1.8 kg $CO_2e/\$_{2002}$ (CMU, 2015). After apportioning from Gunnison County to the Town of Crested Butte via population, the estimated GHG emissions associated with food in Crested Butte are **6,325 mt CO_2e**.

3.4.6 Total Materials and Waste Emissions

Total emissions associated with water & wastewater, waste landfilling, fuel production, cement production, and food production are summarized in Table 5 below.

Table 5: GHG emissions associated with materials and waste in Crested Butte.

Material	Material Flow	GHG Emissions (mt CO_2e)
Water & Wastewater		
Water (kWh)	169,600	119
Wastewater (kWh)	717,331	501
Waste Landfilling (tons)	466	600
Fuel Refining		
Gasoline (gallons)	684,224	1,382
Diesel (gallons)	180,736	480

Cement Production (tonnes)	2,980	2,771
Food Production ($/HH)	$3,245	6,325
Total Materials and Waste GHG Emissions (mt CO_2e)		**12,178**

3.5 Community-Wide GHG Emissions Inventory and Footprint

This effort has allowed the Town of Crested Butte to obtain both, baseline energy and GHG emissions inventory, and footprint. An inventory accounts for in-boundary flows (Scope 1) plus out-of-boundary flows associated with purchased electricity generation (Scope 2). However, communities are greatly dependent on robust sets of infrastructure supply-chains for sustaining local economic development, that considering footprints, which include Scope 3 energy and GHG emissions, are essential for planning. As a result, Crested Butte's GHG emissions inventory (Scope 1 + 2) totaled 40,088 mt CO_2e, or 24.6 mt CO_2e/capita. Upon aggregating out-of-boundary infrastructure supply-chains associated with key materials in Crested Butte (Scope 3), the GHG emissions footprint totals 51,046 mt CO_2e, or 31.4 mt CO_2e/capita. These data are summarized in Table 6 below.

Table 6: Summary of 2017 GHG emissions for the Town of Crested Butte

Sector		(A) Material/Energy Flow	(B) Emissions Factor	(A x B) = GHG Emissions (mt CO_2e)
Residential Buildings	Electricity	30,118,932 kWh	0.74 kg CO_2e/kWh	21,039
	Natural Gas	659,490 therms	5.3 kg CO_2e/therm	3,500
Commercial Buildings	Electricity	5,190,641 kWh	0.74 kg CO_2e/kWh	3,626
	Natural Gas	525,550 therms	5.3 kg CO_2e/therm	2,789
Surface Travel	Gasoline	684,224 gallons	8.87 kg CO_2e/gallon	6,068
	Diesel	180,736 gallons	10.22 kg CO_2e/gallon	1,847
Water & Wastewater	Water	169,600 kWh	0.74 kg CO_2e/kWh	119
	Wastewater	717,331 kWh	0.74 kg CO_2e/kWh	501
Waste Landfilling	MSW Landfilled	472 tons	1.27 mt CO_2e/ton	600
Fuel Refining	Gasoline	684,224 gallons	2.0 kg CO_2e/gallon	1,382
	Diesel	180,736 gallons	2.65 kg CO_2e/gallon	480
Cement Production	Cement	2,980 tonnes	0.93 mt CO_2e/mt	2,771
Food Production	Food	$3,245/HH (2002$)	1.8 kg CO_2e/$_{2002}$	6,325
Total GHG Emissions Footprint (Scopes 1+2+3)				**51,046**
Per Capita GHG Emissions				**31.4 mt CO_2e/capita**

3.6 Benchmarking

Computing total emissions for a community is indeed an essential step towards measuring and continually tracking progress. In order for data to withstand the highest levels of scrutiny however, it must be validated. Therefore, Dr. Chávez employs rigorous levels of data benchmarking to illustrate the alignment of adopted data with what might be expected. The following table, Table 7, shows the results of the data benchmarking process comparing Crested Butte energy and GHG emissions data against high-quality Gunnison County and State data. As a result, this ensures the data can be trusted and used for actionable local planning & engagement.

Table 7: Energy use and GHG Emissions benchmarks. Crested Butte, Gunnison County, and State of Colorado.

Town of Crested Butte Residential Building Energy Benchmarks

	Metric	Unit	2017	Gunnison County (2015)	Colorado (2016)
Residential	Population	people	1,628	16,145	5,538,180
	Households	households	1,083	6,870	2,189,004
	Electricity	kWh	30,118,932	94,749,120	18,834
	Natural Gas	therms	659,490	4,309,512	1,254,160,000
	household electricity use	kWh/HH/mo	2,318	1,149	717
	household natural gas use	therms/HH/mo	50.7	52.3	47.7
	Electricity Intensity	kBTU/HH/mo	7,907	3,921	2,446
	Natural Gas Intensity	kBTU/HH/mo	5,075	7,119	5,167
	TOTAL Residential Building Intensity	kBTU/HH/mo	12,982	11,041	7,614
	Electricity intensity	BTU/sq-ft/mo	4,614		1,010
	Natural Gas Intensity	BTU/sq-ft/mo	2,961		2,634
	TOTAL Residential Building Intensity	BTU/sq-ft/mo	7,575		3,644

Town of Crested Butte Commercial Building Energy Benchmarks

	Metric	Unit	2017	Gunnison County (2015)	Colorado (2016)
Commercial	Employment	jobs	4,208	10,797	3,232,643
	Electricity	kWh	5,190,641	84,519,362	35,903
	Natural Gas	therms	525,550	3,538,905	2,518,600,000
	Annual electricity use	kWh/job/mo	103	652	926
	Annual natural gas use	therms/job/mo	10.4	27	64.9
	Electricity Intensity	kBTU/job/mo	351	2,226	3,158
	Natural Gas Intensity	kBTU/job/mo	1,041	2,814	6,593
	TOTAL Commercial Building Intensity	kBTU/job/mo	1,392	5,040	9,751
	Electricity Intensity	kBTU/sq-ft/yr	44		44.8
	Natural Gas Intensity	kBTU/sq-ft/yr	130		26.7
	TOTAL Comm+Ind Building Intensity	kBTU/sq-ft/yr	174		71.6

Town of Crested Butte Surface Travel Energy Benchmarks

	Metric	Unit	2015	Gunnison County (2015)	Colorado (2016)
Surface Travel	VMT	vehicle miles	15,596,511	153,957,372	46,968
	VMT	miles/person/day	26.25	26	23.23
	Gasoline	gallons of gasoline	684,224	6,754,160	2,150,778,000
	Diesel	gallons of diesel	180,736	1,784,098	596,820,000
	Gasoline per capita	gallons-gasoline/cap	420	418	388
	Diesel per capita	gallons-diesel/cap	111	111	108

Town of Crested Butte Waste Landfilling Benchmarks

	Metric	Unit	2017	Gunnison County (2015)	Colorado (2015)
Landfill	waste landfilled	tons-waste	466	18,647	7,988,308
	normalized waste landfilled	tons-waste/cap	0.29	1.15	1.44

4. 2030 GHG Emissions Forecast

This section summarizes the results from the energy and GHG emissions forecast for Crested Butte to year 2030. Such a forecast is a projection of activities, namely energy use, and the resulting GHG emissions. The forecast is driven by a number of variables, including anticipated demographic changes (e.g., population), economic (e.g., jobs), and technical infrastructural dynamics (e.g., electricity emissions factors). While the 2030 energy and GHG emissions forecast is not intended to be a prediction, it is a tool for local governments to have a reference point to be able to visualize and track the effects stemming from a series of local actions over time.

In this forecast, the sectors defined by the inventory portion of this assessment (see Section 3) have been analyzed. The sectors are: residential buildings, commercial buildings, surface travel, water & wastewater, and solid waste. These five sectors represent the majority of Crested Butte's footprint, but the foundation of these five sectors is such that they offer strong and relatively high-quality local data which allows for energy and GHG emissions forecasting. It is noteworthy to reiterate that this 2030 forecast is for in-boundary activities (Scopes 1+2), only, and does not account for out-of-boundary (Scope 3) activities. Recall, said Scope 3 activities from the footprint are: fuel refining, cement production, and food production; these are not forecasted to 2030.

4.1 Buildings: Residential and Commercial

As previously noted, electricity is supplied to Crested Butte is exclusively from Gunnison County Electric Association (GCEA). At the time of this report GCEA's EF was 0.74 kg CO_2e/kWh. The following were applied affecting to the rate at which renewable targets are met:

> **GCEA** – electricity is supplied to GCEA by Tri-State. A recent annual report indicated Tri-State's regional EF 2030 goals were 0.503 kg CO_2e/kWh (Tri-State, 2015). Thus, this forecast applied an annual linear reduction between current 2015 EF to 2030 goal.

As explained in the next two sub-sections, residential and commercial energy use forecast assumed that the respective energy use intensities remained unchanged from 2017 levels.

4.1.1 Residential Buildings

The residential buildings sector assumed that energy use per capita remained constant from 2017 levels throughout the forecast to 2030. This assumption applied to electricity use (18,505 kWh/cap/yr), and natural gas use (405 therms/cap/yr). Population statistics for Crested Butte between 2005 and 2016 were retrieved from Colorado's State Demography Office (DOLA, 2016), and the computed 2010-16 compound annual growth rate (CAGR) of 1.35% was used project Crested Butte's population to 2030.

As a result of these assumptions, residential building energy use (Figure 2) and GHG emissions (Figure 3) for Crested Butte are project to experience some growth. Residential energy use is forecasted to increase 19%, from 49,447 MWh in 2017 to 58,851 MWh in 2030. Meanwhile, due to only because of GCEA's EF decrease, residential GHG emissions are forecasted to decrease 9.61%, from 24,539 mt CO_2e in 2017 to 22,181 mt CO_2e in 2030. See Table 8.

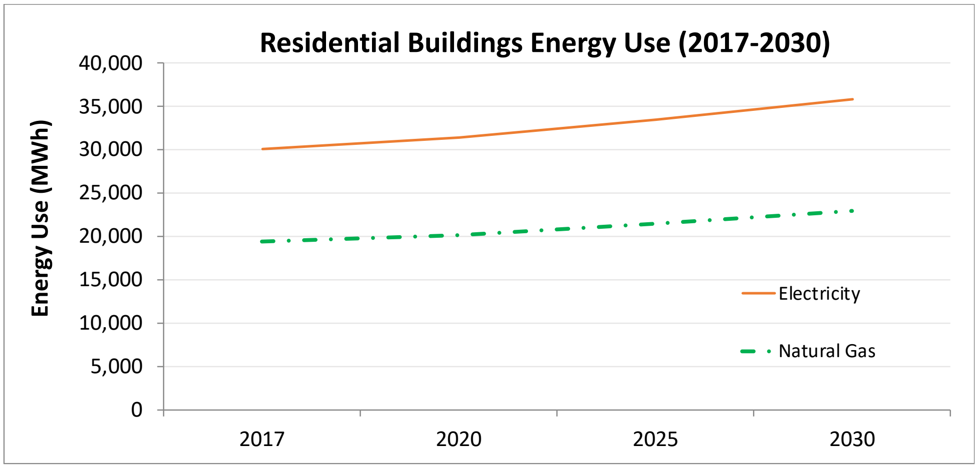

Figure 2: Residential building energy use thru 2030, *in MWh*.

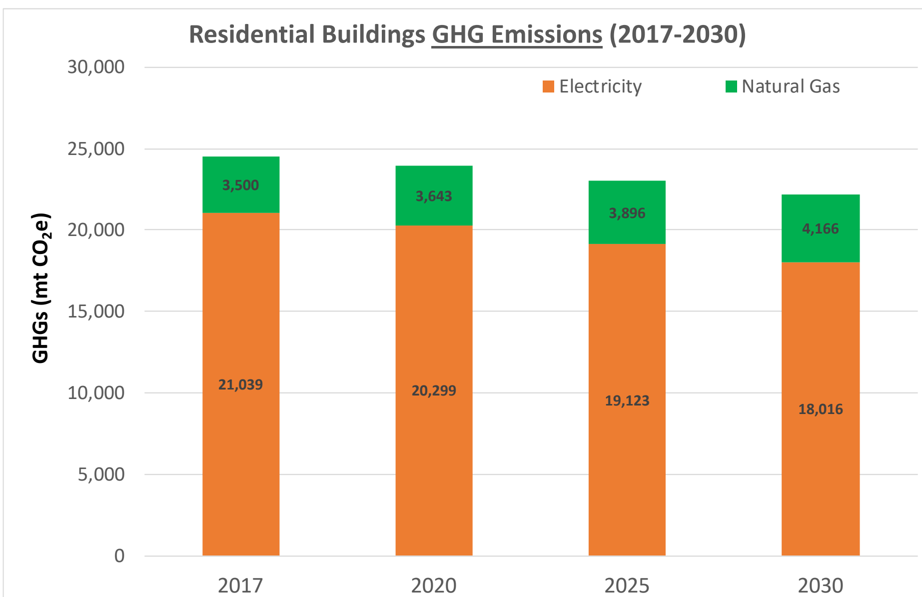

Figure 3: Residential building GHG emissions thru 2030, *in mt CO_2e*.

Table 8: Residential energy use and GHG emissions forecast in five-year increments.

	2017	2020	2025	2030	*% total change (2017 – 2030)*
Residential Energy Use *(MWh)*	49,447	51,475	55,039	58,851	***19%***
Residential Electricity Use (MWh)	*30,119*	*31,354*	*33,525*	*35,847*	
Residential Natural Gas Use (MWh)	*19,329*	*20,121*	*21,514*	*23,004*	
Residential GHGs *(mt CO_2e)*	24,539	23,943	23,019	22,181	***-9.6%***

4.1.2 Commercial Buildings

The commercial buildings sector also assumed that energy use intensity remained constant from 2017 levels throughout the forecast to 2030. This assumption applied to electricity use (1,234 kWh/job/yr), and natural gas use (125 therms/job/yr). Employment statistics for Crested Butte were obtained from the Gunnison Valley Housing Needs Assessment, which also reported a projected 2% annual growth for jobs "North Valley".

As a result, commercial building energy use (Figure 4) and GHG emissions (Figure 5) for Crested Butte are projected to increase. Commercial energy use is forecasted to increase 29.4%, from 20,594 MWh in 2017 to 26,640 MWh in 2030. Meanwhile, commercial building GHG emissions will see a growth of 8.9%, from 6,415 mt CO_2e in 2017 to 6,983 mt CO_2e in 2030.

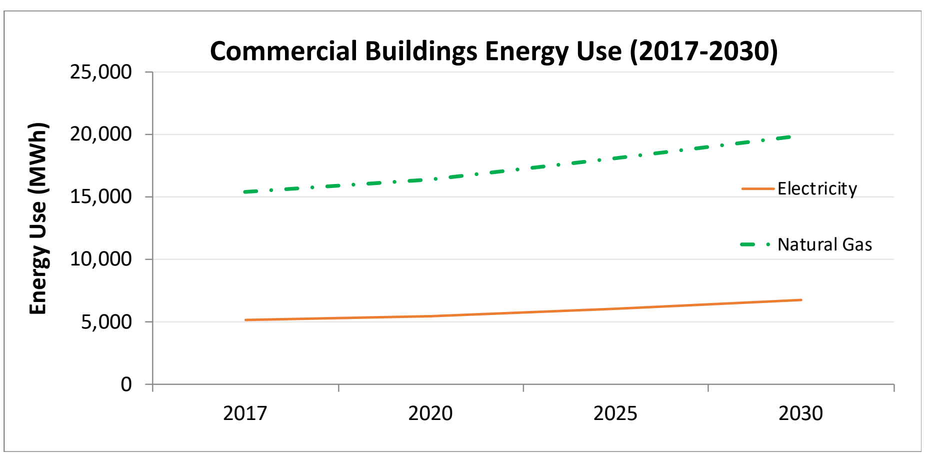

Figure 4: Commercial building energy use thru 2030, *in MWh.*

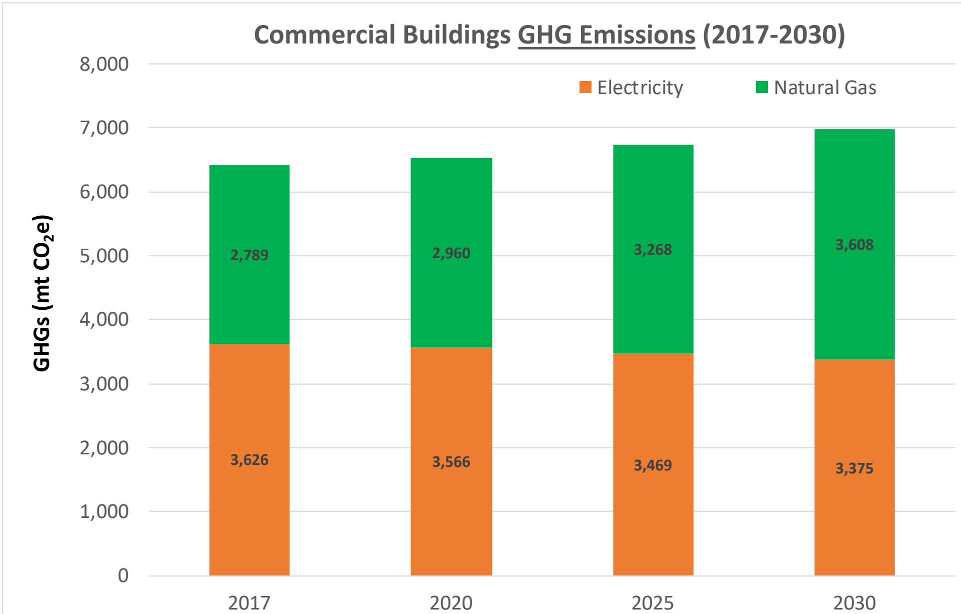

Figure 5: Commercial building GHG emissions thru 2030, *in mt CO_2e*.

Table 9: Commercial energy use and GHG emissions forecast in five-year increments.

	2017	2020	2025	2030	*% total change (2017 – 2030)*
Commercial Energy Use *(MWh)*	20,594	21,854	24,129	26,640	***29.4%***
Commercial Electricity Use (MWh)	*5,191*	*5,508*	*6,082*	*6,715*	
Commercial Natural Gas Use (MWh)	*15,403*	*16,346*	*18,047*	*19,925*	
Commercial GHGs *(mt CO_2e)*	6,415	6,526	6,737	6,983	***8.9%***

4.2 Surface Travel

Surface travel is comprised of private and commercial vehicles, predominantly either users of gasoline or diesel. Emerging from the baseline assessment (described previously) were both VMT/capita and VMT by fuel type for Gunnison County, which were then apportioned to Crested Butte. Meanwhile, national statistics from the U.S. Federal Highway Administration were used to derive growth estimates for gasoline and diesel VMT/capita, respectively, for communities that are both urban and rural – a reasonable depiction of the community (FHWA, 2015). From these data, a CAGR for VMT/cap of 0.04% (gasoline) and 0.87% (diesel) were derived, coupled with Crested Butte population projections, and used for forecasting both gasoline VMT and diesel VMT. Then, after applying fuel efficiencies by vehicle type, forecasted GHG emissions were estimated as reported in Figure 6.

Gasoline GHG emissions are forecasted to increase by 19.6%, from 6,068 mt CO_2e in 2017 to 7,259 mt CO_2e in 2030. Diesel GHG emissions are forecasted to increase by 33.2%, from 1,847 mt CO_2e in 2017 to 2,461 mt CO_2e in 2030.

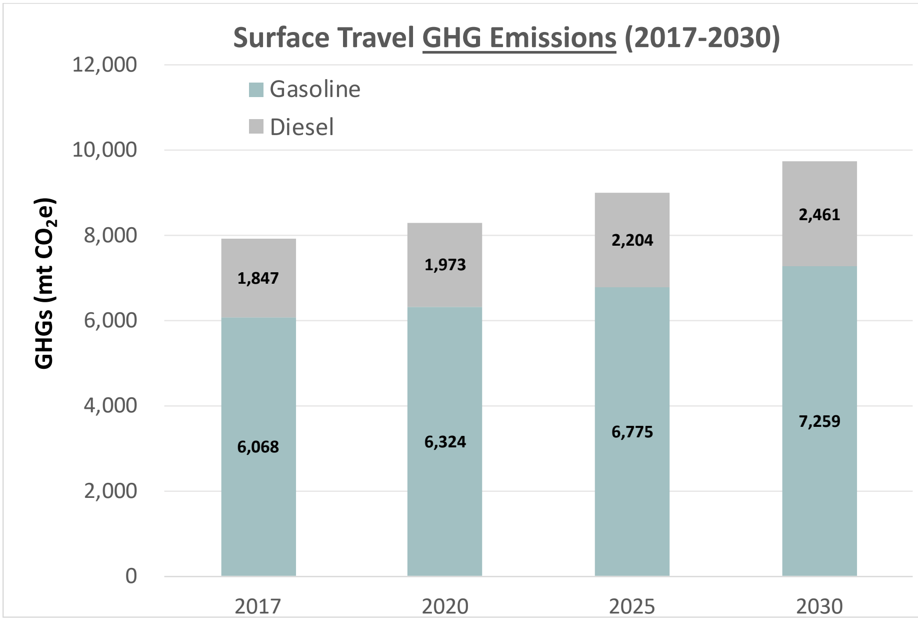

Figure 6: Surface travel GHG emissions thru 2030, *in mt CO_2e.*

4.3 Water & Wastewater

Projecting the use of water & wastewater utility demand into the future assumed the following. First, for water, we assumed that both metered gallons/capita and pumping kWh/gallons hold constant. Second, for wastewater, we assumed that both effluent gallons/capita and water treatment kWh/cap hold constant. As a result, a growing population coupled with a decreasing electricity EF were used to project that in aggregate, GHG emissions in the sector would decrease by 14.4% from 620 mt CO_2e in 2017 to 531 mt CO_2e in 2030.

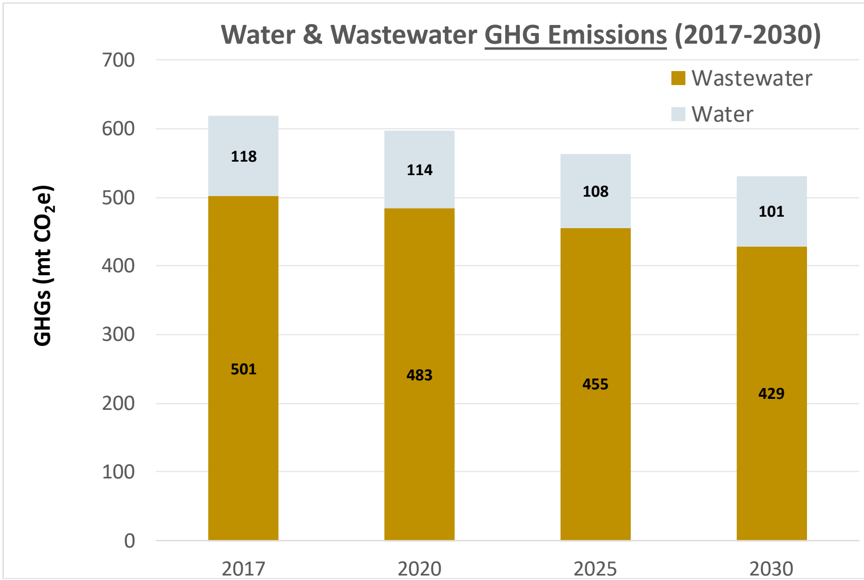

Figure 7: Waste landfilling GHG emissions thru 2030, *in mt CO_2e*.

4.4 Waste Landfilling

Holding the amount of waste per capita constant, population is used to forecast GHG emissions from waste landfilling. It is estimated that waste landfilling GHG emissions would total 714 mt CO_2e in 2030, an increase of 19% from 2017. See Figure 8.

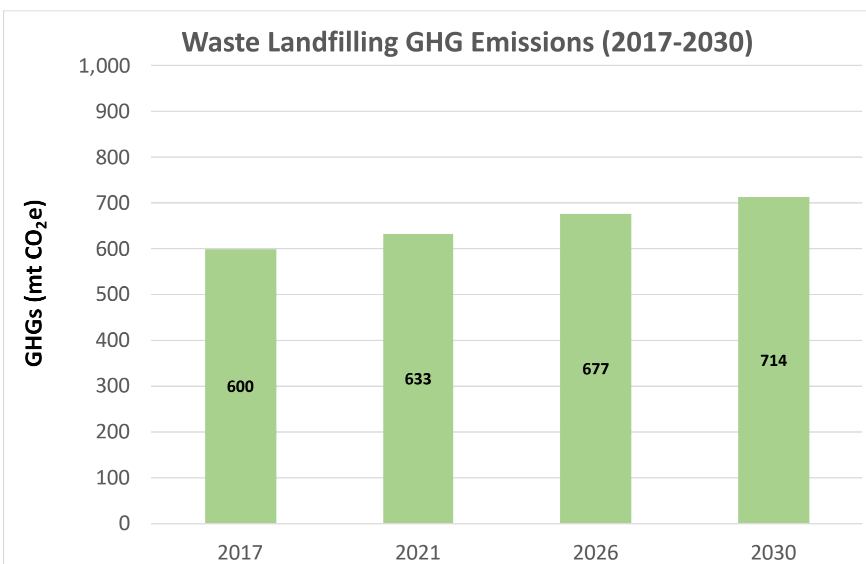

Figure 8: Waste landfilling GHG emissions thru 2030, *in mt CO_2e*.

4.5 Totals and Conclusions

In accordance with the procedures described in this section, the aggregate yields an energy and GHG emissions forecast for Crested Butte's in-boundary activities (Scopes 1+2) to the year 2030. It is important to reiterate that this forecast does not account for out-of-boundary (Scope 3) activities. As result, this forecast estimates that the community's in-boundary GHG emissions will increase a total of 0.1% from the 2017 baseline of 40,088 mt CO_2e, to 40,129 mt CO_2e by 2030. The following table, Table 10, summarizes these projections, and Figure 9 illustrates the same in visual form.

With this 2030 forecast, the community can assess and track a series of actions and their effectiveness over time. While the foundation of this forecast is energy use and GHG emissions associated with Crested Butte, the suite of possibilities extends well beyond energy use and into community development, economic development, social well-being, and many other key dimensions.

Table 10: GHG Emissions Forecast – Summary.

in mt CO_2e	2017	2020	2025	2030	*% total change (2017 – 2030)*
Residential GHG Emissions	24,539	23,943	23,019	22,181	***-9.6%***
Commercial GHG Emissions	6,415	6,526	6,737	6,983	***8.9%***
Surface Travel GHG Emissions	7,915	8,297	8,979	9,720	***22.8%***
Waste Landfilling GHG Emissions	600	625	668	714	***19%***
Water & Wastewater GHG Emissions	620	598	563	531	***-14.4%***
TOTAL In-Boundary GHG Emissions	**40,088**	**39,988**	**39,966**	**40,129**	***0.1%***

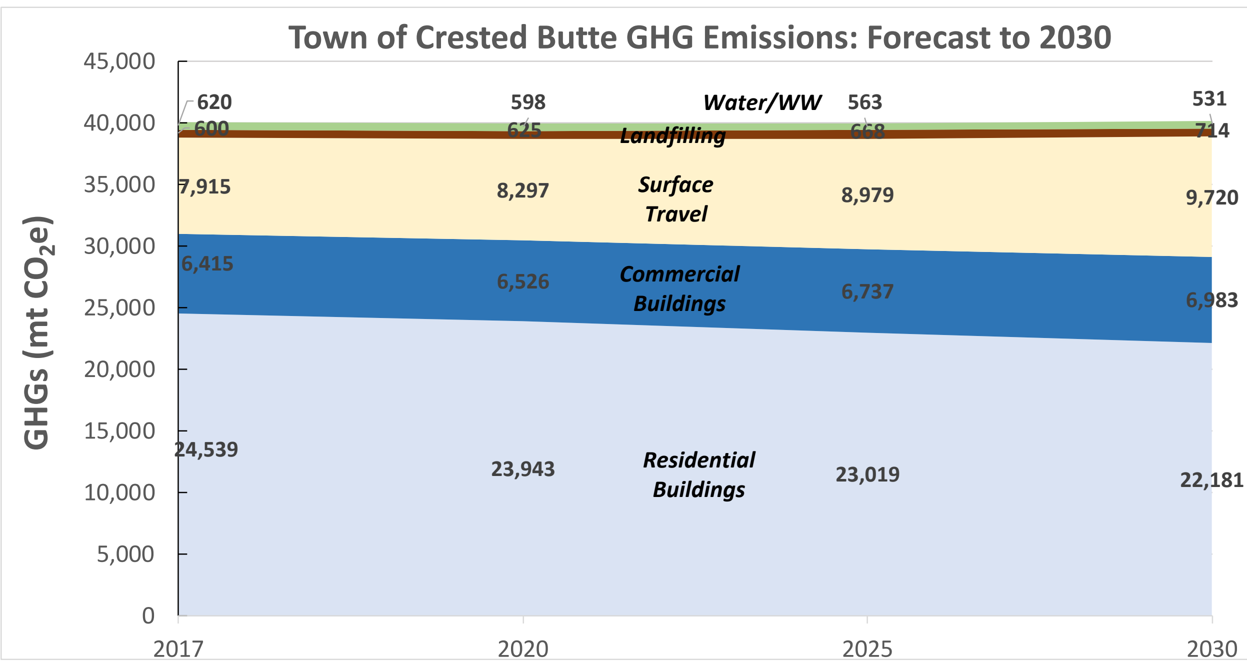

Figure 9: Crested Butte In-Boundary GHG Emissions 2030 Forecast.

Appendix

Appendix A: Community Climate Action Planning

Community Climate Action Planning (CAP), also known as Energy Action Planning (EAP), continues to increase in prominence as communities aim to sustain their livelihoods. While accurately accounting for the full list of communities with CAPs may be a challenging task, local government signatories to conventions whose missions are to assist in CAP development (e.g., Mexico City Pact, ICLEI Carbonn) are approaching ten-thousand communities worldwide. Meanwhile, though a CAP was beyond the scope of this work at this phase, Dr. Chávez's CS2I Lab team are known for their global expertise in creating and executing such frameworks at the ground-level for communities. Next we share ICLEI's Five Milestones, one example of such CAP framework, with minor enhancements made to the milestones by Dr. Chávez.

ICLEI's File Milestones

Milestone One: Inventory and Footprint Energy and GHG Emissions
Milestone Two: Establish Reduction Target
Milestone Three: Develop Climate Action Plan
Milestone Four: Implement Policies & Measures
Milestone Five: Monitor & Verify Results

One other, and recent, framework is offered by UN-Habitat. See Figure 10 below.
As observed from this report, the multi-sectoral baseline & forecast inventory with footprint presented here affords the Town of Crested Butte the opportunity to establish a reduction target (=milestone two), prior to proceeding to imagining a series of plausible abatement possibilities for climate/energy action planning. We offer the following set of recommendations for the Town's consideration:

Recommendation 1. As the Town moves to develop a climate/energy action plan, close partnership with several of the Town's constituents will be imperative. While using this study for the scientific underpinnings, consider a participatory process model with a community stakeholder deliberative advisory group to assist in the identification of plausible actions for your CAP.

Recommendation 2. During the establishing of a reduction target, Crested Butte may be able to leverage Gunnison County's commissioner approved goal of 20% energy efficiency increase by 2030. Such a partnership has the potential of embracing multi-level governance structures to yield streamlined community-wide actions.

Recommendation 3. Our proprietary BAFT (**B**aseline, **A**ccounting and **F**orecasting **T**ool) is designed for communities, for this purpose. Updating and continually tracking energy and GHG emissions via BAFT is not only significantly facilitated via the tool, but it is also necessary, especially following the implementation of abatement policies and measures. Now that Crested Butte has this robust foundation in place, the CS2I Lab team would be honored to assist the Town with updating and tracking progress over time.

Recommendation 4. Given the complexity and multi-dimensionality of environmental challenges, consider developing a coupled mitigation & adaptation climate action plan (MACAP) to maximize resources and potential. Know that Dr. Chávez instructs a graduate course designed to lead community-level MACAPs.

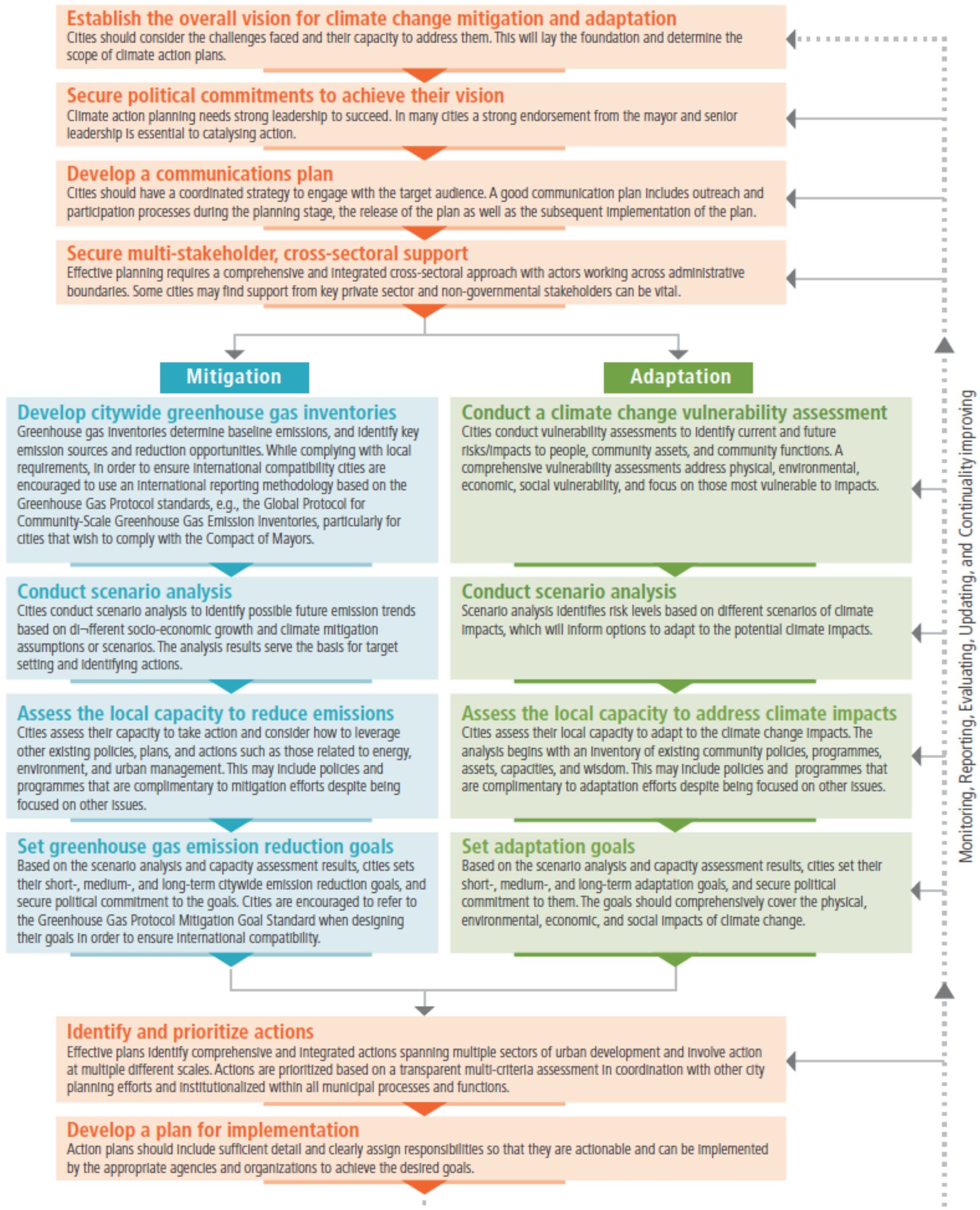

Figure 10: UN Habitat's Community Climate Action Planning Process.

Appendix B: Abatement Possibilities

In over a decade of work, the CS2I Lab team has partnered with over one-hundred communities in the U.S. and across the world on climate action planning type of efforts. Over this trajectory, the team has honed in on five key variables that are relevant for communities in mitigation (or abatement) modeling; those variables are:

1) baseline emissions, by sector *(obtained from work presented here, also found in BAFT)*
2) expected savings from mitigation action *(retrieved from community CAP literature)*
3) level of participation *(theoretical values from literature)*
4) year action was implemented *(community defined)*
5) number of years action is active *(community defined)*

The degree of government involvement will have a direct and significant impact on these variables. For example, voluntary abatement actions, such as building weatherization programs yields minimal expected savings as well as minimal participation. On the other hand, mandated building standards are not only projected to have profound per unit impacts on energy use, but because it is a mandate, far more participation will occur. In general, our research has revealed that voluntary actions yield 5-10% participation, while mandated actions yield over 90% participation. The latter requires much more political will however. While we urge Crested Butte to adopt a participatory process that engages the community in identifying suitable energy and climate actions, below we present a non-exhaustive list of abatement options for the community's consideration as it moves forward. For each action in Table 11 we note the associated sector, the abatement's name, typical savings reported in the literature, and typical participation rates reported in the literature. Recall that Crested Butte's top in-boundary GHG emitting sectors are residential buildings, commercial buildings, and surface travel.

Table 11: Energy and GHG abatement options. A sample from the community-based literature.

Sector	Abatement Option	Estimated abatement per unit *(variable 2)*	Estimated participation rate *(variable 3)*
Residential Buildings	Weatherization outreach	5% of household natural gas	2-5%
	Energy efficiency upgrades (basic#)	3% of household electricity 13% of household natural gas	1-2%
Commercial Buildings	Demand side management (DSM)	2-3% of electricity over 10 years	0.5%
	New green buildings	20-30% of total building energy per square-foot	5% of new sq-ft/yr
All Buildings	Price feedback	~0.5% for each percentage of price increase	2%
Surface Travel	Bicycle mode shifts	30-60% of vehicle miles	Less than 1%
	Fleet upgrades	25-35% of fleet fuel use	Varies

basic upgrades typically provide attic and/or wall insulation and can provide rebates for appliance upgrades. On top of 'basic' upgrades, communities typically also have higher cost home upgrades (i.e., deep retrofits) that include items such as solar heaters, attic fans, windows, etc.

To kick-start the participatory process, we refer the community to the recently published Greenhouse Gas Reduction Toolkit (GHG, 2017) that qualitatively lists a plethora of additional actions. Last, CS2I Lab's second proprietary tool is EMiTT (**E**ffective **Mi**tigation **T**ransitions **T**ool) – our team would be honored to partner with the Town of Crested Butte for the next phases of this work.

Works Cited

ANL. (2016). The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model. Argonne National Laboratory. Retrieved from: https://greet.es.anl.gov

BLS. (2015). Consumer Expenditure Survey. Bureau of Labor Statistics. Retrieved from: https://www.bls.gov/cex/.

BTS. (2016). Aviation TranStats. Bureau of Transportation Statistics.

Chavez et al. (2013). Articulating A Trans-Boundary Infrastructure Supply Chain Greenhouse Gas Emission Footprint for Cities: Mathematical Relationships and Policy Relevance. *Energy Policy, 54*, 376-384.

Census. (2016). American FactFinder. United States Census Bureau. Retrieved from: https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.

CDOT. (2015). Traffic Data Explorer. Colorado Department of Transportation, CDOT. Retrieved from http://dtdapps.coloradodot.info/otis/TrafficData#ui/0/1/0/criteria//51/true/true/.

CDPHE. (2016). Solid waste data and reports. Colorado Department of Public Health & Environment. Retrieved from: https://www.colorado.gov/pacific/cdphe/swreports.

CMU. (2015). Input-Output Life-Cycle Assessment (EIO-LCA). Carnegie Mellon University. Retrieved from: http://www.eiolca.net.

DOLA. (2016). State Demography Office. Colorado Department of Local Affairs. Retrieved from: https://demography.dola.colorado.gov.

EAP. 2009. Energy Action Plan for The Town of Crested Butte. The Crested Butte Energy Action Planning Committee.

EPA. (2014). Emission Factors for Greenhouse Gas Inventories. U.S. Environmental Protection Agency.

EPA. (2016). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. U.S. Environmental Protection Agency.

FAA. (2016). Passenger Boarding (Enplanement) and All-Cargo Data for U.S. Airports. Federal Aviation Administration.

FHWA. (2015). Annual Vehicle Distance Traveled in Miles and Related Data – by Highway Category and Vehicle Type. Table VM-1. Federal Highway Administration. Retrieved from: https://www.fhwa.dot.gov/policyinformation/quickfinddata/qfvehicles.cfm.

GHG. (2017). Greenhouse Gas Reduction Toolkit. The City of Aspen.

GPC. (2014). Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).

Retrieved from: http://www.iclei.org/our-activities/our-agendas/low-carbon-city/gpc.html.

ICLEI. (2012). U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions. Retrieved from: http://icleiusa.org/publications/us-community-protocol/.

IPCC. (2012). Intergovernmental Panel on Climate Change, Fifth Assessment Report (AR5). www.ipcc.ch

NREL. (2016). U.S. Life Cycle Inventory Database. National Renewable Energy Laboratory. Retrieved from: http://www.nrel.gov/lci/.

ORE. (2008). Upper Gunnison River Watershed Greenhouse Gas Emissions Inventory. Office for Resource Efficiency (ORE).

PAS. (2013). PAS 2070, Specification for the assessment of greenhouse gas emissions of a city – Direct plus supply chain and consumption-based methodologies. Retrieved from: http://shop.bsigroup.com/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2070-2013/.

Tri-State. (2015). Tri-State Generation and Transmission Association Annual Report. Reif, K.V.

WARM. (2016). Waste Reduction Model. U.S. Environmental Protection Agency. Retrieved from: https://www.epa.gov/warm.